Proceedings of 2nd International Conference on Mechanical and Production Engineering
Held on 9th – 10th July 2016, in Pattaya, ISBN: 9788193137345

IMPLEMENTATION OF SIX SIGMA: A CASE STUDY IN TEXTILE COMPANY

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***Abstract*— The purpose of this research is to apply six sigma approach through the define-measure-analyze-improve-control (DMAIC) process to improve process in a textile factory. In define and measure phase the warp yarn rupture was found to be a main problem with 4.85% defective products. The causes of the problem were analyzed using cause and effect diagram and the main causes were identified using failure mode and effect analysis. The weaving parameters were found to be major causes of defects. In improve phase, the experimental design was implemented to set the appropriate level of the key parameters, which are warp yarn tension, horizontal distance between backrest roller and warp beam, height of backrest roller, and height of harness frames. A 2^4 factorial design with two replications was performed. The analysis of variance for the designed experiment showed the great influence of warp yarn tension and height of harness frames. From this study, an optimized combination of weaving parameters was determined and set as a working standard. The results showed that the new set of weaving parameters was superior to the original one.**

Keywords—design of experiments, DMAIC; denim fabric, Six Sigma, textile manufacturing

I. INTRODUCTION

Textile industry is one of the main economic sectors, which has an important role in everyday life. Among woven fabrics the usage of denim, as a main part of garment fashion, is greatly increasing every year [1]. Pressure on denim fabric manufacturers has increased due to high competitive markets. Quality and price are considered to be critical success factors. The denim quality depends on fabric quality, machine parameters, and fabric sewability. To enhance quality and reduce production cost the process improvement is a necessity.

Denim is made from a vat dye, the indigo dye, which is applied to cotton fabric in loosely held form in the layers. Generally, there are six main processes to manufacture denim fabric, which are spinning, rope dyeing, sizing, weaving, finishing, and inspection. As far as manufacturing process of denim is concerned, it is similar to that of grey fabric up to the process of weaving with the only difference that in case of denim fabric, it is dyed at the stage of sizing, where as in case of grey fabric, the decision regarding dyeing stage depends upon the finished product. The details of each process are as follows.

The spinning process begins with baled cotton fiber being separated into small tufts. Cotton is delivered through additional cleaning and blending machines to the cards. The main functions of carding are to remove foreign matter and short fibers, form the cotton into a web and convert the web into a rope-like form known as a sliver. Yarn is then spun through open-end spinning or ring spinning. Generally, denim fabric are 3/1 warp-faced twill fabric made from a yarn dyed warp and an undyed weft yarn. Normally dyed and grey ring or open-end yarns are used in warp and weft respectively. Since the warp yarns will be under tension and subjected to stress during weaving as the weft yarn is inserted between them at great speed, it should be well prepared in dyeing and sizing process. In order to reduce damage caused by the many abrasive contacts the warp yarns must endure a chemical preparation; size, is applied to warp yarn prior to assembly on the loom. The size forms a film rendering the yarn more slippery, supple and stronger. Thus it reduces friction, the number of free fiber ends that may interfere with the weaving process and the number of warp yarn breakages [2]. Warp yarns are indigo dyed and sized with two methods. For the first method, threads from several back beams are combined to form a warp sheet and dyed and sized on the same machine. For the other method, threads, about 350-400 in number are formed into ropes. Twelve to fourteen ropes run adjacent to each other through the continuous dyeing unit. After dyeing, the ropes are dried on drying cylinders and then collected in a can. Sizing is then done in the conventional manner before sending to the weaving process. Weaving interlaces the warp, which are the length-wise yarn and the filling, which are the cross-wise yarn. The warp thread is in the form of sheet. The weft thread is inserted between two layers of warp sheets by means of a suitable carrier, such as Shuttle, Projectile, Rapier, Air current, Water current, etc. The selection of carrier depends on the type of weaving machinery used. However, the general weaving machine elements can be shown in Fig. 1. Number 1 to 6 in the Fig. 1 are warp beam, back rest roller, support special drop wires, motor driving the warp let-off, healds (fixed on harness frames), and cloth beam respectively.

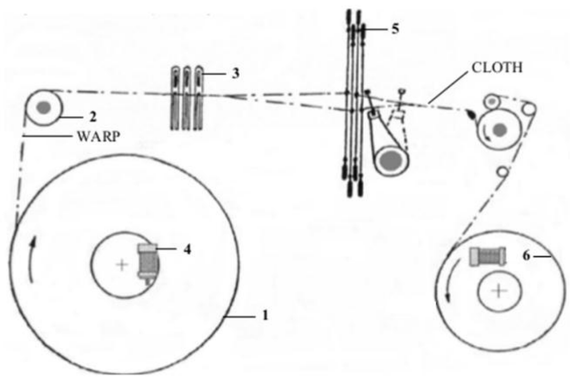
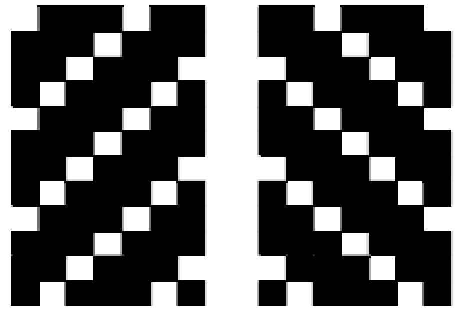


Fig. 1. Weaving machine elements [3]

The finished fabric construction is determined by the number of warp and filling yarns per square inch or centimeter. For example, a typical construction for bottom weight denim may be 62 x 38. This is interpreted as 62 warp yarns per inch of width and 38 filling yarns per inch of length and always in that order. This thread count along with the yarn counts used will influence fabric properties such as weight, fabric tightness, cover, drape, hand, tensile strength, tear strength, and other fabric properties. Numerical notations for different denim designs, such as 3/1, denote what each warp yarn is doing relative to the filling yarns that it is interlacing with. In this case, each warp yarn is going over three picks and then under one pick. This would be verbally stated as 3 by 1 twill or 3 by 1 denim. At the next end, moving to the right, the same sequence is repeated but advanced up one pick. This advancing upward sequence continues, giving the characteristic twill line. In this case, the twill line is rising to the right, and the fabric is classified as a right-hand twill weave. If the twill line is made to rise to the left, then the design is left-hand twill. Broken twills are designed by breaking up the twill line at different intervals thus keeping it from being in a straight line [4]. The 3/1 right-hand twill (3/1 RHT) and 3/1 left-hand twill (3/1 LHT) are illustrated in Fig. 2 (a) and (b) respectively.



(a) 3/1 RHT (b) 3/1 LHT

Fig. 2. Diagram of 3/1 right and left hand twills [4]

After weaving process the final denim fabric, which is wound on a cloth roll, is taken out from weaving machines at particular intervals and checked on inspection machines so that any possible weaving fault can be detected. The woven denim fabrics then goes through various finishing processes depending on customer orders. There are five main properties that determine quality of fabric. They are mechanical properties (such as tensile strength, tear strength, extensibility, etc.), sensory properties (such as smoothing, flexing of fingers, etc.), permeability and insulation properties (such as thermal conductivity, air permeability, etc.), chemical properties (such as burning behavior), and appearance (such as surface characteristics, texture, etc.). Therefore, there are various type of faults or defects from denim manufacturing process that have been studied to solve the problem and improve fabric quality such as shown in [5 -7].

Six Sigma is a well-known and effective data driven methodology that has been implemented in many business applications. Various approaches, tools and techniques, and combinations of Six Sigma with other concepts has been created to improve performance of Six Sigma and fit with a specific business type [8]. Many examples of successful cases are shown such as in [9]. Six Sigma requires process improvement through identifying problem, root causes, process redesign and reengineering, and process management by using a five-phase approach known as DMAIC process [10]. The define phase concentrates on defining the problem and scope, identifying customers and the high impact characteristics or the CTQs (Critical to Quality), and identifying the work effort of the project team. In the measure phase, the data representing the performance of the current process is identified and gathered. The analysis phase focuses on determining the key variables and relating them to the improvement goals. This is the phase where statistical analysis tools and qualitative analysis tools are employed to identify significant causes of variation. At the improve phase, the quality improvement team brainstorms potential solutions, prioritize them based on customer requirements, make a selection, and test to see if the solution resolves the problem. The experimental design, which is a critically important tool for process improvement, manufacturing process development, and new product design is a general well-known tools used in this phase. In general, the objectives of the experiment may include determining which input variables are most influential on the output response or determining where to set the influential input variables so that the output response is close to the desired nominal value, or the variability in the output response is small. Factorial designs are the most efficient technique for the experiments involving the study of the effects of two or more factors. In each replication of the experiment, all possible combinations of the levels of the factors are investigated. Therefore, both of the main effects of the variables and their interactions are examined [11]. Once the solution has resolved the problem, the improvements must be standardized and sustained over time

In this work, DMAIC process is implemented to improve weaving process in a case study company. The main defects in a main product, which is 3/1 RHT pattern denim fabric, is selected to be studied. The influence of weaving parameters is analyzed. To improve the process, a 2^4 full factorial design is implement to find an optimal composition of parameters to minimize the main defects.

II. METHODOLOGY

A. Define and Measure Phase

There are ten main weaving defects, which are given different severity weights, for the selected product in the case study company. They are warp yarn rupture, broken end, warp slub, fluff, slack end, weft slub, knot, tight end, warp knot, and weft cut. The score of defect significance (the number of defects multiplies by severity weight) classified by type is calculated and illustrated in a Pareto chart (see Fig. 3) so that we can identify the main problems to solve. Fig. 3 shows that the warp yarn rupture defect is the main problem, which covers over 82.1% of overall defects, which is 4.85% of the production volume.

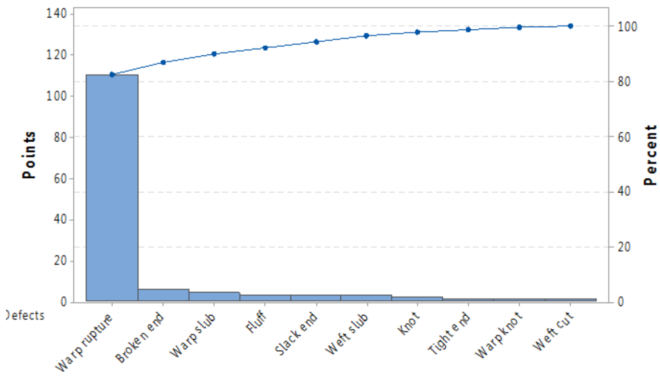


Fig. 3. Pareto chart of weaving defects

B. Analyze Phase

To analyze the input variables or factors that might affect the weaving quality, the process is observed thoroughly. The manufacturing process for denim fabric of the studied company consist of five main steps: spinning, dyeing, weaving, finishing, and inspection. The process starts with spinning the raw material (cotton and polyester) to prepare for warp yarn and weft yarn. After that weft yarns are sent to the weaving department while, warp yarns are rope dyed. The ropes are continuously dyed with grey. Within this process grey color is brought to the fabric and fixed, and finally the excess is washed away. Thirty six ropes are dipped in a series of dye boxes along a grey dye range. Afterward the ropes are dried and set to the beaming department. In the beam dyeing process, warp yarns are wound directly onto a perforated drum. This beam is the dyed in a dye bath under controlled pressure and temperature. In the weaving process, the Suzler G6500 weaving machine are used. The weave pattern can be programmed to the machine. In this research the 3/1 RHT pattern is studied because of the highest sales. In the weaving process the operators adjust the weaving parameters using their experiences accompany with machine manual but there is no working standard for weaving machine setting. At the starting of every new batch, the production run test is conducted. There are four main parameters that the operators have to set before running a new batch which are warp yarn tension, horizontal distance between backrest roller and warp beam, height of backrest roller, and height of harness frames. The current values of these parameters are set at 50 mN, 101 cm, 9 cm and, 13.7 cm. respectively. After weaving process the denim fabric is delivered to finishing department for brushing, singeing eliminate impurities, etc. Finally, it will be inspected before keeping in the store or dispatching to the customers.

The quality improvement team is set to investigate the cause of warp yarn rupture problem. The cause and effect diagram for warp yarn rupture problem is created as shown in Fig.4. The risk priority number (RPN) of each cause, which is a multiplication of severity score, occurrence score, detection score, is calculated using failure mode and effect analysis (FMEA) as explained in [12].

The incorrect setting weaving parameter is found to be a major cause with risk priority number (RPN) = 7 x 7x 9 = 441. The four main weaving parameters or factors are investigated. The test levels are presented in Table I.

C. Improve Phase

A 2^4 full factorial design with two replications is used to carry out the experiment to test the two following hypotheses. The first hypothesis is to test whether factors (treatments) affect the response. The other hypothesis is to determine whether treatments interact.

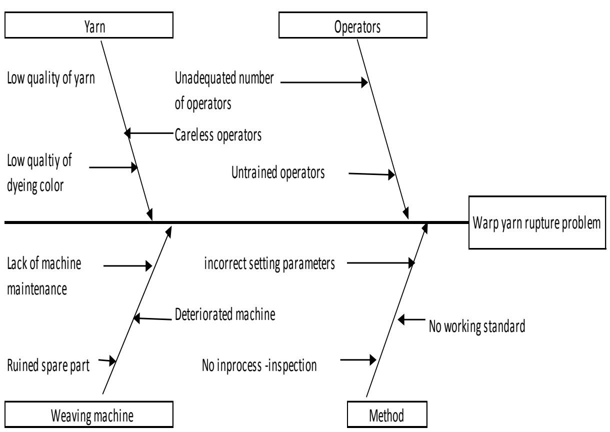


Fig. 4. The cause and effect diagram for warp yarn rupture problem

TABLE I. LOW LEVEL AND HIGH LEVEL VALUES OF THE FACTORS

Factors	Low Level (-1)	High Level (+1)
A: Warp yarn tension (mN)	50	100
B: Horizontal distance between backrest roller and warp beam (cm)	101	110
C: Height of backrest roller (cm)	5	9
D: Height of harness frame (cm)	13.3	13.7

In each set of treatments, one batch of denim with size of width x length = 1.55 x 150 m^2 is used. The length of warp yarn rupture is measured as a response (Y). The run order for each set of treatments is created randomly by using the "create factorial design" function in MINITAB. The results of the experiments are statistically analyzed by using analysis of variance at a level of significance □ = 0.05. After that, the experimental results are interpreted and the optimal combination of factors is set.

D. Experimental Verification and Control Phase

Before using the optimal combination as a working standard, another set of experiments is performed to verify the replicability of the experiment.

III. RESULTS AND DISCUSSION

This part is divided into two sections. The first section expresses the experimental results and interpretation of results. The other section shows the results of experiment verification.

A. The Experimental Results and Analysis

The length of warp yarn rupture of 32-run experiments are summarized in Table II. Before making a conclusion from the ANOVA table, the assumption of experimental or residual error, which is normal and independently distributed, should be examined by analyzing the residual plots illustrated in Fig. 5.

TABLE II. THE LENGTH OF WARP YARN RUPTURE FOR ALL COMBINATIONS (UNIT: m)

C: Height of Backrest Roller (cm)	**D: Height of Harness Frames (cm)**	**A: Warp Yarn Tension (mN)**			
		50		100	
		B: Horizontal Distance Between Backrest Roller and Warp Beam (cm)			
		101	110	101	110
5	13.3	105.3	104.0	6.3	7.3
		106.8	107.0	6.3	5.8
	13.7	105.0	106.0	77.5	105.0
		111.3	105.8	72.5	62.3
9	13.3	107.0	104.5	4.3	7.8
		105.8	105.8	5.8	5.0
	13.7	106.0	106.3	89.0	105.0
		106.0	109.8	99.3	85.0

From Fig. 5, the Normal Probability Plot shows that the residuals are in linear form. It can be concluded that the data distribution is a normal distribution. Likewise, the Histogram shape also shows that the data distribution is normal. The other two graphs show that the residual is independently distributed because the plotted data is distributed randomly. Thus, it can be concluded that the residual is normal and independently distributed. After assumption verification, the ANOVA table for the experiment summarized in Table III is considered.

From Table III, the factors A, D, and AD interaction significantly affect the response because p-values are less than the level of significance α = 0.05. Because AD interaction has a significant effect, only the AD interaction plot (shown in Fig. 6) is used and the main effect plots are ignored to set the level of factors. To determine the level of factor B and C The main effect plot of factor B and C (shown in Fig. 7) are considered accompany with the suitability of application.

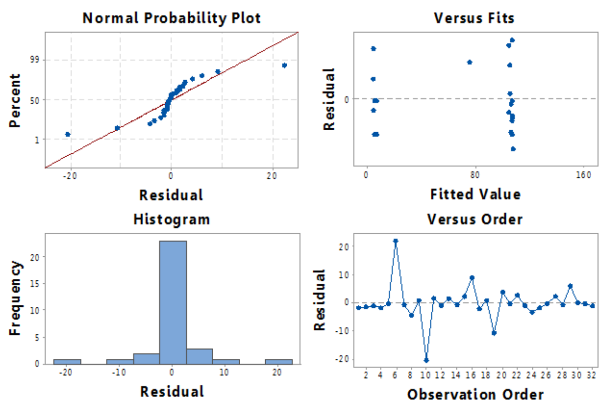


Fig. 5. Residual plots for Y

TABLE III. ANOVA FOR THE LENGTH OF WARP YARN RUPTURE RESPONSE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
A	1	28695.1	28695.1	392.84	0.000
B	1	10.4	10.4	0.14	0.710
C	1	106.0	106.0	1.45	0.245
D	1	13499.3	13499.3	184.81	0.000
A*B	1	21.5	21.5	0.29	0.594
A*C	1	106.0	106.0	1.45	0.245
A*D	1	12690.2	12690.2	173.73	0.000
B* C	1	1.2	1.2	0.02	0.899
B* D	1	11.0	11.0	0.15	0.703
C* D	1	127.0	127.0	1.74	0.205
A* B * C	1	12.8	12.8	0.18	0.681
A* B * D	1	5.1	5.1	0.07	0.795
A* C * D	1	127.0	127.0	1.74	0.205
B* C * D	1	1.9	1.9	0.03	0.875
Lack-of-Fit	1	24.1	24.1	0.32	0.582
Pure Error	16	1217.7	76.1		
Total	31	56656.4			

According to AD interaction plot in Fig. 6, factor A should be set at a high level while factor D should be set at a low level in order to minimize the length of warp yarn rupture. According to Fig. 7, factors B and C should be set at low level. Although the level of factor C needs to be changed from the current setting value, it makes easier to commonly use with the other denim patterns. Moreover, the two-factor interaction of all factors in Fig.6 shows that this combination is the best combination to minimize the response. According to AB and AC interaction plots, when factor A is set at a high level, factors B and C should be set at low levels. In the same way, when factor D is set at a low level, factors B and C should be set at low levels by using BD and CD interaction plots. Finally, BC interaction plot shows that the low level of factors B and C give minimum length of warp yarn rupture. Therefore, the recommended weaving condition for the weaving machine is using 100 mN of warp yarn tension, horizontal distance between backrest roller and warp beam at 101 cm, 5 cm. height of backrest roller, and 13.3 cm. height of harness frames.

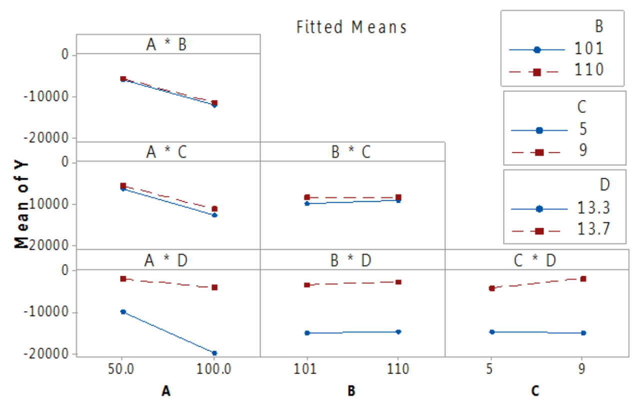


Fig. 6. Two-factor Interaction plot for Y

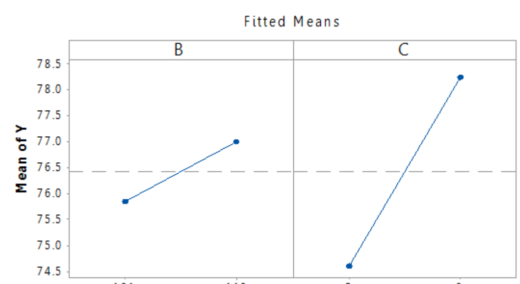


Fig. 7. Main effects plot of factor B and C for Y

B. *Results of Experimental Verification*

To verify the repeatability of the results, another set of experiments where factor A is set at a high level and the other factors are at low levels is conducted. Twenty batches of denim were used for these experiments. The result shows that there is no warp yarn rupture found. After result confirmation, the optimal combination is set as a working standard.

IV. CONCLUSION

Six Sigma can be used to improve product quality. Using experimental design to set the optimal condition of weaving machine reduces warp yarn rupture defects, which were found to be a main defects. Four weaving parameters composed of warp yarn tension, horizontal distance between backrest roller and warp beam, height of backrest roller, and height of harness frames were investigated. Warp yarn tension and the height of harness frame were found to be significant parameters affecting the length of warp yarn rupture. The appropriate weaving machine parameters are setting 1.0 N of warp yarn tension, horizontal distance between backrest roller and warp beam at 101 cm, 5 cm. height of backrest roller, and 13.3 cm. height of harness frames. However, the process parameters and the tested level in this work were set under company constraints. The results can be applied only to the similar process. For future research, this work can be extended to working standards and manuals for the other processes. The various parameters, such as the weaving patterns, the type of fabrics, etc. should be investigated.

V. REFERENCES

[1] R. Nayak, “Sewing performance of stretch denim,” *J. of Textile and Apparel Technology*, vol.6, no.3, pp. 1-9, Spring 2010.

[2] A. Walters, D. Santillo, P. Johnston, *An overview of textiles processing and related environmental concerns*, Greenpeace Research laboratories, UK., ch.2. June, 2005.

[3] G. Castelli, S. Maietta, G. Sigrisi, and I.M. Slaviero, *Reference books of textile technologies weaving*, fondazione ACIMIT Italian Association of Textile Machinery Producers Moral Body, Milan, Italy, pp. 28, October 2000.

[4] Cotton Incorporated, *Denim fabric manufacturing*, North Carolina, USA., 2004.

[5] M. Tunak, A. Linka, “Simulation and recognition of common fabric defects,” In *Proc. the 13th International Conference on Structure and Structural Mechanics of Textiles*, Liberec, Czech Republic, p. 363-370, 2006.

[6] E. Haghighat, S. M. Etrati, S.S.Najar, “Evaluation of woven denim fabric sewability based on needle penetration force,” *Journal of Engineered Fibers and Fabrics*, vol.9, issue 2, 2014.

[7] S.S. More, S.P. Maruti, “Performance improvement of textile sector by implementing quality Six Sigma (QSS),” *International Journal of Application or Innovation in Engineering & Management*, vol.2, issue 12, 2013.

[8] Tjahjono, B., Ball, P., Vitanov, V. I., Scorzafave, C., Nogueira, J., Calleja, J., Minguet, M., Narasimha, L., Rivas, A., Srivastava, A. et al., “Six sigma: a literature review”, *International Journal of Lean Six Sigma*, vol. 1 issue 3, pp.216–233., 2010

[9] Al-Refaie, A. and Al-Hmaideen, K., “Six sigma management and grey relational analysis to improve performance of tableting process”, *International Journal of Productivity and Quality Management*, vol. 15, issue 1, pp.57–71., 2014

[10] Gupta, N.,“An application of dmaic methodology for increasing the yarn; quality in textile industry”, *J. Mech. Civ. Eng*., vol. 6., issue 1, pp. 50–65, 2013.

[11] D.C. Montgomery, *Design and Analysis of Experiments*, John Wiley&Sons, Inc. USA., ch 5, 2001.

[12] D. H. Stamatis, Failure Mode and Effect Analysis: FMEA from Theory to Execution. 2nd ed., Milwaukee: American Quality Press, Wisconsin, USA., ch.2, 2003.